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Apparatus for creating a local reduction in wave height.

The present invention relates to apparatus and methods of locally reducing the effect of waves at sea or on other large bodies of water, principally by reducing the wave height. More particularly the present invention relates to a structure, preferably a floating structure, disposed in use at or near the water surface which can in use reduce wave energy.

The installation and maintenance of offshore structures such as wind turbines and marine energy extraction systems are affected by the waves at the work site. The waves cause the vessels from which work is being undertaken to move, which causes inconvenience to workers and, if wave conditions are beyond certain levels, can be dangerous. The time while waiting for calm conditions which permit safe operations is expensive and negatively affects the productivity of the operation being carried out. Such an operation may be, for example, installing the large numbers of machines, which together constitute an offshore wind or wave power station. These vessel motions can also cause dangerous conditions to develop during lifting, assembly and access operations. It is also increasingly recognised that prolonged work at offshore locations can have a damaging effect on wildlife at the work site since such wildlife is not used to human presence and activity.

This has lead those carrying out work offshore, such as offshore wind farm developers and others, to propose large jack-up vessels to remove or avoid the effects of wave motions on vessels working at an offshore work site. As their name suggests, these vessels avoid the effect of the waves by jacking the vessel partially up or lifting it clear of the sea surface. Such vessels are expensive to construct and operate. Nevertheless, several offshore projects have been delayed by wave action in the construction / installation phases, and the costs of such delays are even more acute when expensive equipment is forced to remain non-operational.

This present invention seeks to produce a temporary floating wave energy absorber which, when deployed in front of the vessel undertaking offshore works such as installation or maintenance, provides a reduction in the wave height in the area of the work vessel. The resulting so-called wave shadow of calmer water permits offshore operations to be conducted by a much cheaper floating vessel, in a safer environment and without the costs associated with waiting for calm offshore conditions. An important characteristic of the apparatus of the invention is its temporary nature. The apparatus can be used at a given work site and, when no longer required there, can be taken up and deployed again elsewhere.

Prior Art

US 2,388,171 describes a series of floating blocks to provide wave protection. The blocks are anchored to the seabed. Protection from the waves is provided by a combination of drag and reflection.
US 5,702,203 describes a floating "V" shaped breakwater which provides protection by deflecting the incoming waves.
US 3,969,901 describes a floating breakwater which acts to reflect the wave energy.
US 3,952,521 describes a portable floating wave "tripper" which acts to cut the wave into sections disturbing the flow.
US 4,468,151 describes a fixed structure for damping sea waves as they approach a sea wall.
US 4,027,486 describes a floating breakwater which acts to reflect the wave energy.
US 2002/0085883A1 describes a floating breakwater which acts to reflect the wave energy.
GB 1 580 326 describes an array of floating flexible bags which rely on internal fluid movement through restrictions in the bag to remove wave energy.
WO 02/26019 describes an array of interconnected elements arranged to hang vertically downwardly from the sea surface. The elements include chambers and channels to create back-pressure and jets to disrupt wave flow.

GB 2 006 689 describes a network of liquid filled tubes which is adapted to float at the water surface.
EP 0 283 631 describes an array of plates for floating on the surface, the plates being connected at their margins by flexible joining pieces.

Many of the prior art designs rely on reflection of the wave energy as the waves impact on structure. In large waves and storm conditions the amount of energy in the wave can cause damage to the structure, or can require the design to be prohibitively expensive. Several of the designs rely on multiple anchors to hold the breakwater in position which is inconvenient and potentially time consuming during installation. Some prior art designs utilise large elements which need to be fitted together to provide the breakwater. This can take a significant amount of time, making such systems unsuitable for temporary installations. Commonly the prior art uses structural mass to provide reaction to wave-imposed forces which in turn requires the breakwater to be heavy and thus cumbersome to transport and store.

According to a first aspect of the present invention there is provided apparatus for creating a local reduction in wave height comprising:
an upper surface portion operatively disposed at or near the water surface, and
a plurality of drag inducing elements disposed below the upper surface portion, which elements are collapsible or compressible when the apparatus is not in use.

Preferably the upper surface portion comprises a plurality of flexibly linked buoyant or semi-buoyant sections.

Alternatively, in another preferred embodiment, the upper surface portion may comprise a single sheet of flexible buoyant or semi-buoyant material.

In a particularly preferred embodiment, the apparatus of the invention comprises a plurality of flexible fluid retaining structures disposed thereon.

Preferably said flexible fluid retaining structures comprise a network or grid of pipes or tubes. Preferably also said fluid is maintained in said flexible structures under pressure. To this end preferably at least one pump for supplying fluid to said flexible fluid retaining structures. Most preferably said fluid is water.

In one form of the invention at least some of said drag inducing elements comprise shaped elements formed from a compressible material.

Alternatively, at least some of said drag inducing elements comprise collapsible drogue anchors.

Preferably at least some of (and most preferably all of) said drag inducing elements are inflatable with an inflating fluid, preferably water.

In a particularly preferred embodiment the inflating fluid for said inflatable drag inducing elements is supplied from said flexible fluid retaining structures.

In another particularly preferred embodiment, the leading end of the apparatus in inclined downwardly with respect to incident waves.

According to a second aspect of the invention there is provided a system for deploying and recovering an apparatus for creating a local reduction in wave height comprising:

an apparatus as defined in the first aspect of the invention
a deployment vessel
a storage device on said vessel for said apparatus, and
means for paying out and recovering said apparatus.

Preferably said storage device is a storage reel about which the apparatus is wound when not in use.

The invention also relates to methods of deploying the apparatus and system defined above. In such methods, the apparatus is deployed from a deployment vessel, such as by paying-out the apparatus from a storage reel. The apparatus is located in a desired position and maintained in that position by mooring the apparatus to the deployment vessel, to buoys or to other suitable structures. Where compressible shaped drag inducing elements are used, these in a compressed state during storage and are allowed to expand on deployment, e.g. through their own natural resilience. Water is supplied to the flexible fluid retaining structures (primarily pipes and tubes) to provide a desired stiffness to maintain the shape of the apparatus in use, and also a required mass. Where the apparatus has inflatable shaped elements, water is supplied from the flexible fluid retaining structures to the shaped elements. After use, the apparatus is recovered by taking it up onto the deployment vessel, e.g. by winding the apparatus around a suitable reel. The shaped elements are compressed or deflated by draining the inflating fluid (water) therefrom, as appropriate, so that the overall size of the stored apparatus is minimised. Inflating fluid (water) is also drained from the flexible fluid retaining elements for storage of the apparatus.

The invention seeks to provide a method and apparatus for the temporary deployment offshore, such as at sea, of a structure which acts to reduce the wave height. The deployment of the apparatus is temporary or casual in the sense that it can be deployed when and where needed and recovered after use for deployment at the same location at a different time or at a different location. Preferably, the apparatus of the invention acts to reduce the wave height by inducing viscous drag between the structure of the apparatus and the circulating water molecules as the wave travels along beneath or around the apparatus. The apparatus is most preferably collapsible and may be either buoyant or semi-buoyant, or may be non-buoyant and suspended by suitable means at set depth in the water column.

In preferred forms, the apparatus takes the form of one or more mat-like structures (hereinafter "mats") having a relatively small depth in relation to the length or width of the mat. The or each mat is typically deployed so that its width dimension is at 90

degrees to the predominant wave direction, i.e nominally parallel to the line of the incident wave crests. The width of the mat is generally significantly smaller than its length. In other words, the length (i.e. major dimension) of the mat is disposed generally parallel to the predominant wave direction. The mat(s) is (are) deployed from a suitable structure such as a deployment vessel and in some arrangements the arrangement is such as to ensure the waves pass under the leading edge of the mat. In some preferred arrangements, the drag induced by the movement of the waves acting on the mat trails the mat out from the deployment structure in the direction of wave movement. Once the wave starts to pass under the mat viscous drag between submerged elements of the mat progressively removes the potential and kinetic energy in the wave, so reducing the wave height. In other preferred arrangements, the leading edge of the mat (i.e the edge which the waves meet first) may be partially submerged. This has an effect similar to that of a beach, causing the waves to break over the mat.

It is anticipated that a typical mat may be 50 to 100m long and work over a width of wave front of about 100m. The wave shadow behind the mat is estimated to be about 100m long before diffraction will cause the wave front to re-establish. Preferably the length of the mat is selected so that it extends to at least about one wavelength, or to approximately whole numbers of wavelengths. In this way, drag forces may be cancelled out so reducing mooring forces of the mat.

The apparatus of the invention removes energy progressively and in a self limiting way, limiting the storm loading and providing a more cost effective design. The apparatus of the invention further may advantageously make use of drag from the waves to hold it in the correct orientation. This makes installation quicker and more suitable for short term and temporary operations. The mat forming the apparatus of the invention can be stored, for example on suitably arranged rotary storage reels. Once in the desired location of use the mat is unwound onto the sea surface. When in storage on the reels the mat volume can minimised by constructing the apparatus so that to at least some degree it can collapse from its use condition. In this way

temporary use and recovery of the apparatus of the invention at a given location are both quick and cost effective.

In a preferred arrangement, during operation the shape of the mat can be maintained using fluid pressure, preferably a liquid and ideally water, in closed or partly closed structures, i.e. flexible fluid retaining structures such as pipes or tubes. The fluid retaining structures may be closed, or may provide a fluid through-flow path which is preferably constricted to limit the out-flow of fluid. The fluid retaining structures, in particular tubes, are arranged at intervals on the apparatus, for example, passing across and along the length of each mat in a network or grid. Fluid, most preferably water, is pumped into the fluid retaining structures. In this way, a desired pressure within the flexible fluid retaining structures is maintained. The enclosed fluid within the flexible fluid retaining structures also provides mass to the mat to help maintain shape and correct operation of the drag which is induced. This mass is conveniently removed prior to transport and storage simply by draining out the water.

Pumped water may be jetted out from the mat into the wave to further disrupt the wave circulation and reduce the wave height.

A plurality of three-dimensional shaped formations is desirably added under the mat structure to increase the surface area and complicate the flow path for the water molecules in the wave, thereby increasing the drag induced on the passing wave. These formations may include but not be limited to:-

a multiplicity of self inflating drogue anchors;

a multiplicity of three dimensional shapes which may preferably be inflated by the pumped fluid from the flexible fluid retaining structures. These shapes act to increase drag and flow path length under the mat. In other variations of the apparatus, the shapes may be self-inflating such as of a compressible resilient foam material;

surface coatings or applied layers on the mat and/or the inflated shapes to provide increased drag action. The applied layers can preferably comprise bristles, or other or frond-like or fibrous relatively thin and flexible elements.

By making the three dimensional shapes disposed beneath the mat compressible or collapsible, an important advantage is achieved in term of the temporary use of the apparatus. That is, when the apparatus is taken up from its position of use for transport and/or storage, the shapes can be collapsed by draining the inflating fluid (water) from them (if they are inflatable) or otherwise compressed. This means that the apparatus of the invention can be conveniently stored on a suitable reel or the like which would, with a non-collapsing/compressing structure, be impossible because of the resulting bulk of the apparatus.

In one preferred arrangement the apparatus can be deployed in 20 or 30m wide mat strips to reduce the weight of each section. The drag action of the wave as it passes away from the deployment / anchoring structure keeps the mat spread out over the surface of the water.

The uses of the invention may include but not be limited to:-

short term protection from waves for shore, near shore and offshore work where waves and vessel motions limit operations;
temporary harbours for loading and unloading equipment at sea;
short term protection for beach landings of personnel and/or equipment;
offshore wind turbine installation, maintenance and decommissioning;
wave or tidal power equipment installation, maintenance and decommissioning.

For a better understanding of the invention, and to show how the same may be carried into effect, reference will be made, by way of example only, to the following drawings in which:

Figure 1 illustrates schematically the deployment of an apparatus according to the invention from a vessel so providing a "wave shadow" for a work vessel;

Figure 2 shows a the deployment vessel and apparatus according to the invention on a larger scale;

Figure 3 shows schematically a series of mat structures according to the invention deployed from a vessel;

Figure 4 shows schematically in detail the construction of one embodiment of the apparatus of the invention;

Figure 5 shows a schematic view of the underside of one embodiment of the apparatus of the invention; and

Figure 6 shows schematically a side view of another embodiment of the invention.

Referring now to the drawings, the mat-like structure (10) of the invention is initially retained on a storage reel (12) on a deployment vessel (14) or other suitable structure. The mat structure (10) is deployed in a chosen location to provide in use a wave shadow (i.e. an area of calmer water where the wave height is reduced) for a work vessel (16). The mat structure (10) is deployed in this embodiment at the water surface. As can be seen from Figure 3, the apparatus of the invention may comprise a plurality of adjacently located mat structures (10a-10d) deployed from a barge (18) to provide a desired width for the wave shadow area.

Figure 4 shows an embodiment of the apparatus of the invention which comprises a surface portion in the form of a series of floatation units (20) which may take the form of individual rigid or semi-rigid sections linked together by suitably linking means. At least some of the linking means should provide a flexible joint between individual sections. Alternatively said surface portion may comprise a substantially

continuous sheet of flexible material consisting primarily of a flexible flotation material such as one of the more mechanically strong foam materials known in the art. The foam material may in this case be laminated to one or more strengthening and/tear resistant material layers. Flexible fluid retaining structures comprising longitudinal and transverse water pipes (22) (24) act to provide structural shape and mass to the apparatus. Of course, these pipes (22, 24) could be filled with a fluid other than water, but water is more convenient.

Disposed under the floatation elements (20) are shaped drag-inducing elements (26) which may be self-inflated or inflatable by means of pressurised fluid. The shaped elements (26) may thus be collapsed or compressed for transport or storage of the apparatus. Where the shaped elements (26) are inflatable, the fluid in the flexible fluid retaining structures may advantageously be used as the inflating medium for the shaped elements (26). Thus, each inflatable shaped element (26) is preferably in fluid communication with a pipe (22, 24). The shaped elements (26) act to increase the water flow path (i.e. its length and/or complexity) and so increase drag on the apparatus as the water of the waves passes around the apparatus. The shaped elements (26) are shown in the Figures as having the shape of a prism but the apparatus in not limited to that particular shape for the shaped elements (26). The shaped elements (26) may be identical, or a mixture of different shapes may be used.

Flexible strain members (28) are provided to carry drag forces from the collapsible underwater shaped elements (26) into strain members in the mat structure (20) and thence to the deployment vessel (14) or other mooring means. The flexible strain members may comprise metal or plastic strip material of suitable strength.

Figure 5 shows an example of an underside structure of a mat (10) according to the invention including a plurality of shaped elements (26). The surfaces of these shapes are preferably covered with structures which act to further increase drag of passing water molecules. These structures may, for example, be formations depending from the surface of the shaped elements (26). The formations are preferably flexible (or at

least non-rigid) and may be resilient. Suitable examples include such as bristles or fronds of material (e.g. of a plastic, rubber or rubber like material) or the like. Alternatively, the shaped elements (26) may be absent with the underside of the mat (10) directly covered (at least partially) with drag-increasing flexible formations. The flexible stain members (28) are most preferably disposed beneath the shaped elements (26) in a criss-cross or grid-like (e.g. reticulate) arrangement and assist in retaining the shaped elements (26) in their intended location.

In other embodiments of the invention the shaped elements (26) may be replaced, at least in part, with a plurality of layers of reticulate material such as fishing net suspended below the floatation elements (20) so that drag is provided by water passing in and out of the net weave.

In another alternative embodiment the shaped elements (26) may be replaced, at least in part, with a series of drogue anchors constructed from a flexible material. As a wave passes a drogue anchor, the water molecules flood the parachute of the anchor causing it to open out and so providing increased drag and an increased water molecule flow path.

Figure 6 shows another preferred variation of the invention in which the leading end 110 of the mat 100 is inclined downwardly so that the leading portion 112 of the mat 100 presents a sloping face to the incident wave. The length and angle of leading portion 112 are not shown to scale. The sloping face has effects analogous to a similarly sloping beach in that the wave is caused to break over the sloping surface, contributing significantly to the dissipation of the wave energy. In Figure 6, the direction of the incident waves is indicated by arrow A.

Although not specifically shown in all the drawings, mooring means are provided as required to retain the apparatus 10, 100 in its position of use.

The apparatus of the invention has been shown in tests conducted in a wave tank to provide as much as a 50% reduction in wave height and a 70% reduction in wave power. Taking as an example work on offshore structures off the coast of East Anglia, UK, for a vessel able to work safely at a wave height of 1m or less, without the apparatus of the invention typically available working time is only 60% or 219 days per year. The apparatus of the invention would in these circumstances provide a dramatic improvement to 92% availability, or 337 days per year.